THE AMERICAN
JOURNAL OF PSYCHOLOGY
Founded by G. STANLEY HALL in 1887

VOL. XXX JULY, 1919 No. 3

EYE-MOVEMENT DURING FLUCTUATION OF ATTENTION.[1]

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Fluctuation of attention has been the subject of a great amount of experimentation and discussion. Theories are numerous and diverse and in spite of the increasing bulk of work done in the investigation of the phenomenon no theory has been generally accepted. One of the more recent systematic investigations of the attention wave was carried out by C. E. Ferree. In two articles published in this JOURNAL[2] he proposed a peripheral theory which, because of its plausibility and the quantity of data adduced as evidence for it, presents a challenge to the holders of other theories. His contention was that fluctuations of attention "are in reality, simply adaptation phenomena somewhat obscured by special conditions. Adaptation is, itself, a continuous phenomenon, but its continuity is interfered with by eye-movement, blinking, etc. Through these influences, probably essentially through that of eye-movement alone, it becomes an intermittent process, whether the stimulus be liminal or intensive, provided that proper areas be used."[3]

[1] From the Psychological Laboratory of the University of Michigan.
[2] C. E. Ferree: (1) An Experimental Examination of the Phenomena Usually Attributed to Fluctuation. Am. J. of Psych. XVII, 81 and (2). The Intermittence of Minimal Visual Sensations. *Am. J. of Psych.* XIX, 58.
[3] Ibid., (1) 83.

Taking Ferree's position as a typical example of peripheral theory, the present research was undertaken with the purpose of testing his theory by investigating in a more exact manner than he had done, the eye movements occurring during fluctuations of attention. This problem was suggested by Professor Pillsbury whose constant aid and advice have been indispensable.

A formal statement of Ferree's thesis is as follows: "(1) The intermittence of minimal visual sensation is a phenomenon of adaptation. (2) Adaptation is rendered intermittent chiefly through the influence of eye-movement. (3) Eye-movement interferes with adaptation in three ways. (a) It decreases the total time of stimulation. The more eye-movement there is, the less intensive will be the impression made upon the retina. (b) It affords time for the after-image to die away, or (in terms of adaptation) it gives opportunity for restoration, proportional to the length of time during which the stimulated area is relieved. And (c) more immediately, it determines or influences the washing or streaming over the retina of some material capable of directly affecting the visual processes."[4]

If one accepts the evidences which Ferree adduces the thesis logically follows; however, the method employed in securing the crucial data does not seem adequate. The crux of the whole problem is the question of the distribution and extent of eye-movement during the fluctuation of the minimal visual sensation. To determine this matter Ferree used the following arrangement. "The shifting of the negative after-image during fixation afforded a method somewhat rough, but adequate for our purpose. Colored strips, 5 mm. x 40 mm., were used as stimuli. They were pasted on a background of white card-board, with the shorter dimension in the plane in which the eye-movement was to be investigated. The determination of frequency then became merely a matter of recording the appearance of the after image to the right or left or above or below the stimulus, separate series being made for both planes. For the determination of range of movement, narrow strips of paper of the same brightness as the background were placed successively 2, 4, 6, 8, etc., mm. from the stimulus, and only those movements recorded that caused the after-image to shift to or beyond these strips. The strips were so inconspicuous as not to attract the eye away from the fixation point; still, it was not difficult to judge when the after-image reached, or passed beyond them. Some

[4] Ibid., (2) 129.

periods were given up wholly to the investigation of eye-movement alone, thus determining the type in general; while again the eye-movement tracing was alternated with the corresponding fluctuation tracing, in order to establish a more immediate connection between the eye-movements in either plane and the phases of visibility and invisibility in that plane. Doubtless it would have been better to have the eye-movement recorded while the fluctuation was in progress could this have been done without interfering with the normal course of the phenomenon. As it was, however, enough results were obtained to render conclusions safe as to the type of the observer."[5]

What Ferree regards as a slight disadvantage, i. e. the inability to record eye-movement while fluctuation was in progress, seems quite clearly to offer a difficulty which must be overcome if his theory is to be put upon a convincing basis. Before the casual relation of eye-movement to the fluctuation of attention can be established the temporal relations involved must be definitely determined. The most that can be done by Ferree's method of approach is to obtain suggestive approximations. In a problem of this kind there can be no substitute for simultaneous records of eye-movements and fluctuations of attention. Now Dodge's method for photographic registration of eye-movements can be employed without interfering with the normal course of the fluctuation of attention. The present investigation is a study by photographic registration of the eye-movements occuring during the fluctuation of attention and was carried through with the conviction that Ferree's thesis must stand or fall on the evidence supplied by satisfactory simultaneous records of fluctuations and eye-movements.

A full description of the apparatus is unnecessary since a detailed statement of the technique is to be found in Dodge's study of visual fixation.[6] A few sentences on its general arrangement will suffice. The experiments were performed in a dark room. The observer was seated with head held immovable in a head rest providing a support for the forehead and a rigid mouthpiece of wood and sealing wax to be gripped by the teeth. Directly before him at a distance of 169.5 cm. a square of light was exposed, both area and intensity of which could be varied. The intensity could be controlled by the observer himself. The area used, unless otherwise indicated,

[5] Ibid., (1) 113.

[6] R. Dodge: An Experimental Study of Visual Fixation. *Psych. Rev.| Mon. Supp.* VIII, 4.

was 1 cm. At the observer's right an arc lamp projected a beam through a needle-point aperture, a plate of blue glass, and a system of lenses focussing upon the cornea of the left eye at an angle of approximately 30° to the line of sight. The reflected beam entered an enlarging camera and fell upon a photographic plate in a Dodge falling plate device. The rate of fall of the plate varied in these experiments from .8 cm. to 2.38 cm. per second. The form of the eye record was a straight line on the plate when the eye remained motionless. Horizontal or oblique eye-movements produced horizontal or oblique deflections of this line. The observer recorded the appearances and disappearances of the fixation light by means of a telegraphic key in circuit with an induction coil, the secondary terminals of which led to a sparkgap mounted in a tube closed at one end and fitted at the other end with a short focus lens. The tube was so adjusted within the camera box that a tap of the key caused a spark to record itself on the photographic plate at the side of the spot of light from the eye. A single tap of the key signaled an appearance or the beginning of a visibility phase, two taps signaled a disappearance or the beginning of an invisibility phase.

A few remarks are necessary concerning the control of conditions during the experiments. In the first place, as has been indicated, the observer controlled the intensity of the fixation light. No attempt was made to keep this intensity constant from experiment to experiment but only to make certain that the fluctuations should occur as regularly and as clearly as possible for each observer. Since all observations were made in the dark it was necessary to allow the subject's eyes to become dark adapted before any records were taken. A further interval was allowed in which the subject adjusted the fixation light and practiced recording the fluctuations. Since the arc lamp was in operation during this time the conditions were exactly those under which the records were later taken. In addition to this practice period at the beginning of each sitting at least one entire preliminary sitting was allowed for practice, the first records being taken the day following or in some cases two days later.

Distraction was eliminated as far as possible. The humming of the arc lamp was soon ignored while the noise of the induction coil vibrator was reduced by enclosing the coil in a box. To determine the extent of the distraction caused by the signaling itself two controls were run for each subject. First, the intensity of the fixation light was increased until no fluctuations occurred and a record was obtained in which the ob-

server signaled at a tempo approximating that of the usual periods of fluctuation. The effect of distraction which we wished to observe, if present, would be indicated by marked horizontal displacements of the approximately straight line in the record of the eye during fixation, these displacements corresponding to the positions of the signals. None of these records showed appreciable movements of the eye at the moments when the signals were given. Secondly, a set of controls was run for each subject in order to determine whether the eye-movement record during fluctuation would be modified were signaling abandoned. These controls were also negative.

Fatigue presented no problem since its onset could always be detected by the experimenter, for when fatigue was pronounced the beam reflected from the cornea would persistently drift out of the field of the camera lens, necessitating repeated readjustments of the apparatus. The observer was in each experiment cautioned to report fatigue as soon as it was noticed and in all such cases the experiment was at once discontinued. It ought also to be mentioned that each observer was thoroughly informed as to the nature of the problem and of the operation of the apparatus. This was deemed necessary in order to secure the fullest coöperation of the subject during the course of the investigation. The records were taken on 5x8″ rapid dry plates, two records on each plate. From 4 to 12 plates were taken at a sitting depending on the capacity of the subject. The records from each sitting constitute a series. In calculating the results each series was treated separately.

It now remains to describe the procedure followed during a typical sitting i. e. in obtaining a series of records. The room being darkened the observer was seated with head firmly fixed in the head rest. The arc lamp was set in operation and the necessary adjustments of the apparatus made. The observer then varied the intensity of the fixation light until it appeared to fluctuate clearly and regularly. He signaled each appearance and disappearance thus enabling the experimenter to decide when the fluctuations were occurring with sufficient regularity to begin recording. At the proper time the experimenter indicated by the word "now" that a plate was being exposed. The end of the exposure was similarly indicated. Immediately a second exposure of the plate was made and at its conclusion the introspections for the two records were given. After each two records and while a new plate was being prepared for exposure the observer was allowed an interval of rest. (Usually from 12 to 14 records were taken at a sitting.) The controls

were usually run at the end of the series though this rule was not invariably followed.

Results were obtained from the following seven subjects: Professor Pillsbury (P), Dr. Benedict (Bd) Head of the department of Ophthalmology in the Mayo Clinic, Rochester, Minn., Mr. Ross (R), Mr. Breininger (Br), Mr. Stayer (S), Miss Gordon (G), and Miss Wylie (W), students of psychology. Messrs. Cooley and Bowen, and Miss Wylie gave much time and patience in serving as subjects in the preliminary stages of the work. W supplied several records of eye-movement during fluctuation without signals. These records are of value in showing the type of eye-movement in her case. From R 4 series were obtained including the records of about 80 fluctuations (counting the number of fluctuations for each series as one less than the number of appearances), from Bd 3 series or about 48 fluctuations, from P 3 series or about 30 fluctuations. In the case of P one series of records was destroyed before the results could be computed. The character of the records of this series was observed to be the same as regards type of eye-movement as for those of the remaining two series. The records from Br, S, and G were taken merely to confirm the general conclusions rendered certain by the data from R, P, and Bd. From Br 2 series or 13 fluctuations were obtained; from G 1 series or 13 fluctuations, and from S 1 series or 5 fluctuations.

The scope of this investigation has been quite rigidly limited to a study of the presence or absence of eye-movement during the fluctuation of attention. We desired simply to know whether or not eye-movements regularly accompany the fluctuation of attention, and if they do, whether or not they regularly occur at or near the beginning of the visibility phase.

The subjects showed two distinct types; first, those who exhibited frequent eye-movements during the fluctuation of attention. Of these again there were two kinds. The eye-movements were either evenly distributed over both the visibility and invisibility phases or they occurred mainly during the invisibility phase. In the second type of subjects the eyes remained relatively fixed during the fluctuations of attention. When movements of the eyes did occur, they occurred at random.

Let us consider, first, the data obtained from R. An examination of Plate I, R_1 and R_2 will show that in his case with the onset of the invisibility phase the eyes exhibited large and frequent movements which were discontinued at the return of the visibility phase, or soon after it. These movements

were seldom less than 85′ of arc and on the average (as may be seen from a later table) ranged from somewhat less than 130′ to movements exceeding 300′. Any one of these movements of R's eyes during the invisibility phase would have been sufficient to cause the return of the visibility phase were the fluctuations really causally dependent on eye-movements since the arc subtended by the fixation light on the retina under the conditions of the experiment was but 20′.

The introspections given by R were illuminating. R was convinced that in his case "eye-movement caused the return of the visibility phase." The invisibility phase was a period during which a "sense of effort was experienced" and "this effort seemed effective in bringing back the light." The disappearance of the light, on the other hand, was a "passive experience." Of course, it can be seen from the records R_1 and R_2 that the eyes did move during the invisibility phase but they moved a number of times. R's introspections contain, however, no detailed account of how large or frequent were the eye-movements but only that the eyes did move and that "as a result" the light returned. The form of record shown in the plate persisted essentially unchanged until the fourth series. Here the group of movements so characteristic of R's invisibility phases showed a gradual reduction in range and number. This might have represented a transition in R's type of eye-movement during fluctuation of attention. However, speculation is useless as the records had to be discontinued at this point.

P, also, exhibited eye-movements during fluctuation of attention. However, a comparison of P_1 and P_2 with R_1 and R_2 (Plate I) shows a fundamental difference. In P's case the movements occurred at fairly regular intervals and were distributed evenly over both visibility and invisibility phases. Moreover the type of record shown in P_1 and P_2 persisted throughout the three series of records without any essential modification.

P's introspections also differed from R's in an important respect. No particular effort or strain was noted as occurring during the invisibility phase although the eyes were constantly in movement at this period as in R's case. An interesting experiment was performed during one of P's sittings. Records were taken when he endeavored to keep his eyes fixed on the light and to prevent, as far as possible, all eye-movement. Other records were taken in which no attempt was made to influence eye-movement. The effect of this attempted control of eye-movement during fluctuation is apparent if one com-

pares P_1 with P_2. The type of record in the two cases is the same, but in P_2 the eye-movements seem to be restricted as compared with those in P_1. It was impossible for P to modify essentially his type of eye-movement during fluctuation of attention.

The following table gives the records from R and P, two series each, tabulated for comparison. The values given are, of course, averages. In computing, 1/5 second was allowed for reaction time in determining the positions of the signals with respect to the eye record line. This correction does not appear in the records reproduced in Plates I and II.

Subject	Vis.	Eye-movement		Invis.	Eye-movement	
	sec.	No.	Range (mm)	sec.	No.	Range (mm)
R	2.92	1	3.2	2.05	3	1.2—3.2
R	2.84	1	3.7	2.07	2	1.4—2.9
P	2.37	4	1.0—1.9	2.16	3	1.0—1.8
P	1.81	3	1.1—1.5	2.13	3	0.9—1.9

The magnitude of the eye-movements is to be found in the column headed "Range" and is given in terms of the lateral displacement of the eye record line measured in millimeters. The range represents the average of the smallest and the average of the largest movements occurring during the visibility and the invisibility phases respectively. In order to translate these displacements in millimeters into eye-movements expressed in minutes of arc five determinations were made. Records were taken with subject P when he moved his eyes to and fro between fixation points separated by 2, 4, 6, 8, and 14 cm. respectively and at a distance of 162 cm. from the observer. These determinations are as follows:

Displacement of the line in mm.	Eye-movements in minutes of arc.
0.8	42
1.0	86
1.3	130
2.1	170
2.5	296

Take, for example, the value 3.2 mm. from the "Range" column above. This corresponds to a movement exceeding 296′ of arc. It will be remembered that the fixation light at a distance of 169.5 cm. from the observer subtends an arc of approximately 20′ on the retina. Of course, interpolation is unsafe in changing millimeters to minutes of arc but these five determinations will serve their purpose in showing that for

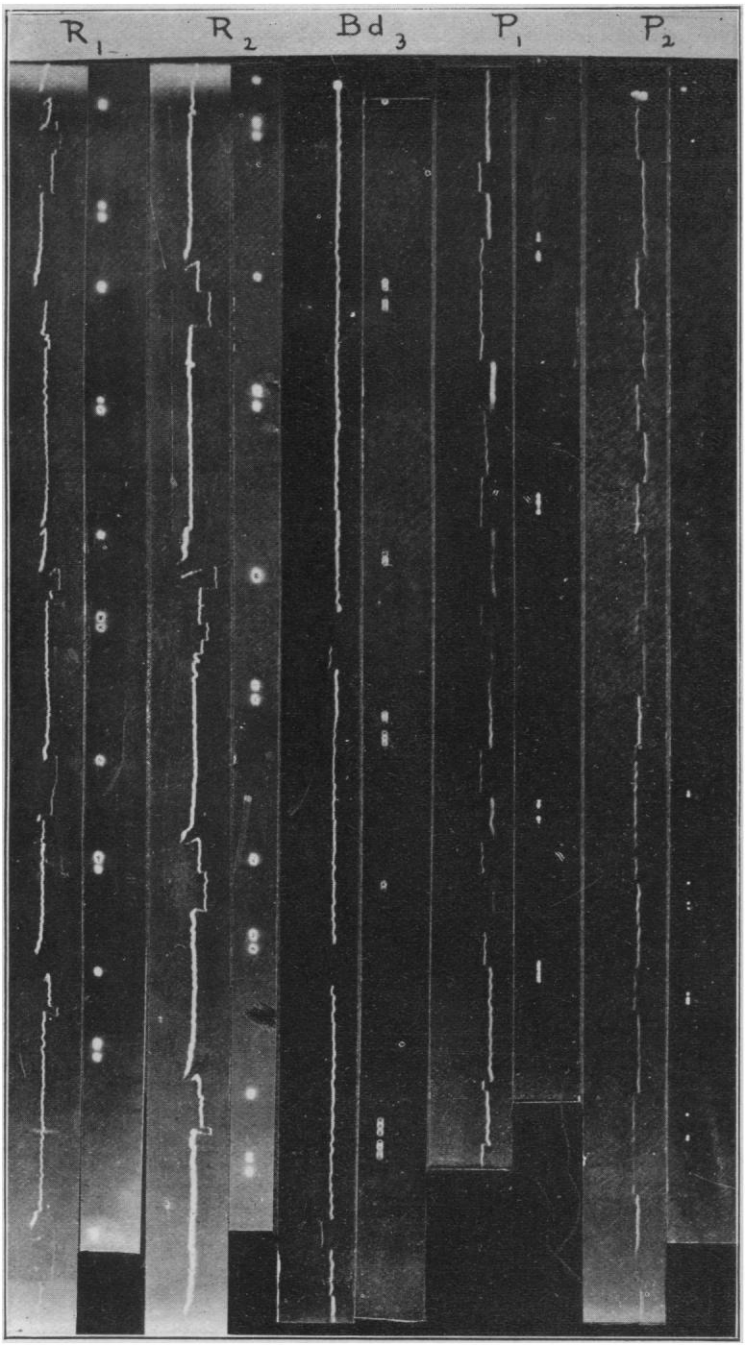

PLATE I.

Note: Plates I and II are to be read from the bottom upward. The signals are at the right of their corresponding lines. One dot signals the appearance, two dots the disappearance of the fixated light. The lines of signal dots have been adjusted to correspond accurately to the eye-movement records.

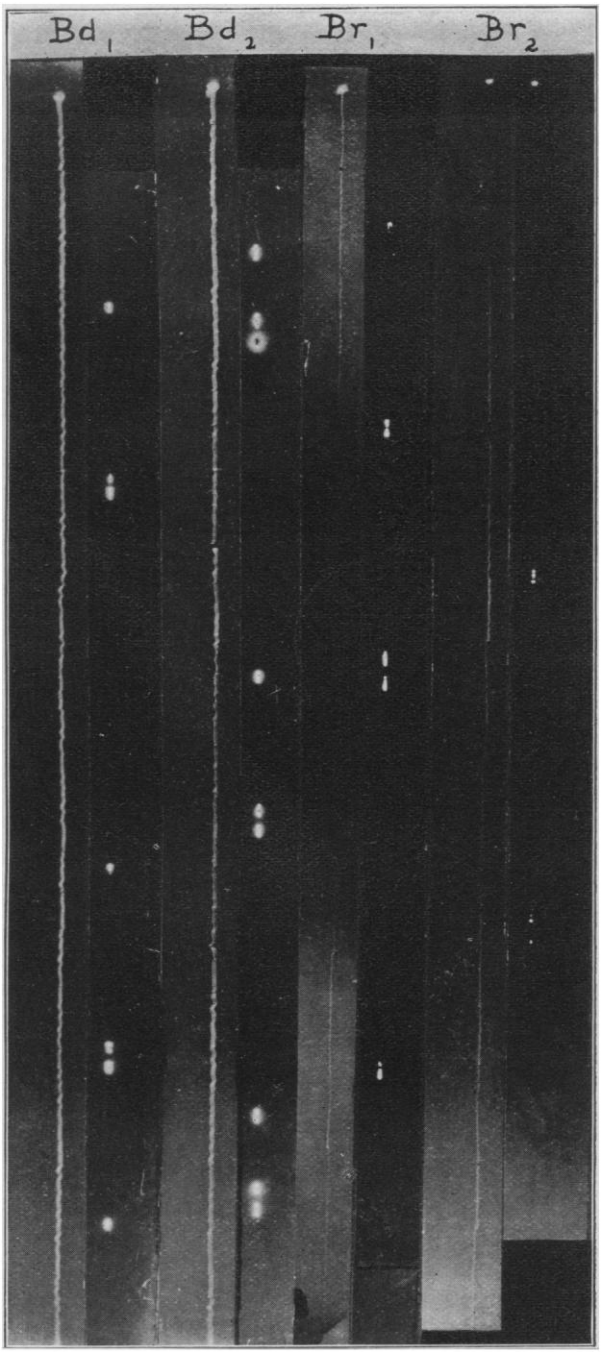

PLATE II.

both P and R eye-movements regularly occur during the invisibility phase which are much larger than those required by Ferree's thesis and yet two or three such movements do not suffice to cause the recurrence of the visibility phase. The records of S and W are similar in a general way to those of P; i. e. eye-movements are more or less evenly distributed.

We come now to the second class of subjects. In the cases of both Bd and Br the eyes remained relatively fixed during fluctuation of attention. This is clearly seen if one compares Plate II with Plate I. To be sure, the lines Bd_1, Bd_2, and Br_1, and Br_2 present a wavy appearance, but this is due, as Dodge found, to pulse and head movements.

Bd's eyes were even steadier than Br's, in whose case a few random movements did occur. Bd had remarkable control of his eyes. Early in the experiments he reported a strong tendency toward "searching movements" during the invisibility phase and he believed that when he allowed himself to make these eye-movements that they "caused the light to reappear" and that refraining from them lengthened the invisibility phase. A special group of records was therefore taken. In certain of these records Bd was instructed to make the searching eye-movements. In the other records he maintained as rigid fixation as possible. Unlike P, Bd was able actually to control his eye-movements during fluctuation of attention. Plate I, Bd_3 shows a record of his eye-movements during fluctuation of attention when the "searching movements" were voluntarily made. We have here a type of eye-movement resembling that of R and disproving Ferree's thesis just as definitely as do R's records; for large eye-movements at the beginning of the invisibility phase do not cause the immediate onset of the visibility phase.

On the other hand the cases in which the subject's eyes remain relatively fixed, viz. Bd_1, Bd_2, Br_1, and Br_2 are just as disastrous for an eye-movement theory of the fluctuation of attention since no prominent eye-movement occurs in these cases at, or near the beginning of, the visibility phase.

In Br's case, voluntary control of eye-movement during fluctuation was even less noticeable than in P's records. Br's eyes remained fixed during both rigid fixation and relaxation, i. e. when the subject observed the fluctuations of attention in a passive manner. However, Br's attempt voluntarily to maintain rigid fixation during fluctuation exhibited itself to introspection in a curious fashion. In such cases the reappearance of the light after invisibility came as a shock, similar, as Br described it, to the experience of one riding in a train which

has entered a tunnel and then after an interval suddenly emerges. Br also noted a slight tendency during the invisibility phase to try to "bring the light back." G's records were of the same general type as those of Bd and Br.

Two further points should be mentioned. The average fluctuation times for the subjects Bd and Br were as follows:

Bd when eyes moved.....	av. vis. 2.01 sec. av. invis. 2.68 sec. for 4 fluctuations.
Bd no eye-movement.....	av. vis. 3.47 sec. av. invis. 5.83 sec. for 24 fluctuations.
Br.....	av. vis. 8.69 sec. av. invis. 5.83 sec. for 11 fluctuations.

The individual differences were so great and the cases so few that no inferences have been drawn from the durations of visibility or invisibility phases under the various conditions and among the various subjects.

The effect of variation of the area of the fixation light on eye-movements during fluctuation of attention was determined for subject Bd. The type of eye-movement exhibited by Bd remained essentially unaltered when 4 mm.^{2} and 9 cm.^{2} areas were employed in place of the usual area of 1 cm.^{2}

In conclusion, we can say that fluctuations of attention are not causally dependent on eye-movement; for (1) some subjects exhibit eye-movements during fluctuations of attention and these movements occur during the invisibility phase without causing the immediate recurrence of the visibility phase and (2) some subjects show little or no distinguishable eye-movement during fluctuation and where the eye-movements do occur, they occur at random. No prominent eye-movements regularly occur at, or near the beginning of, the visibility phase. These results are incompatible with the assumptions of an eye-movement theory of the fluctuation of attention.